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Where Do You Think You Are? Effects of Conceptual Current Position on Spatial Memory Performance

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Testing spatial memory within the same environment used for learning produces interference between one's immediate representation of current position and the to-be-retrieved position. In a series of 3 experiments, we show that "current position" and its influence on memory performance can be driven by conceptual factors in an ambiguous testing situation. First, we demonstrate that simple instructions about the testing conditions—"you are in the space" versus "imagine the space"—determined whether a participant showed interference from current position, reflecting the effect of one's conceived position in space on long-term memory retrieval. In addition, we show that when instructions motivate this use of current position under ambiguous conditions, the position assumed is defined by the last known position rather than the learning position. We account for these results by suggesting that current models of spatial memory need to incorporate both the perceptual and conceptual testing environment, malleable versus stable features, and the interaction of current position with long-term memory.

Keywords: spatial cognition, spatial memory, updating, memory representation

Imagine standing at the door of your kitchen in darkness. If you were asked to point or walk to where the coffee maker is located, you would likely use your current position to think about the location first and then act on it. In the absence of conspicuous landmarks (and even without any visual inputs), humans and other animals can often keep track of changes in position and orientation in the environment with respect to a fixed reference point, a process referred to as path integration (for review, see Berthöz et al., 1999; Cornell & Heth, 2004; Loomis, Klatzky, Golledge, & Philbeck, 1999). More critically, people have great difficulty ignoring movement in space when doing path integration, even when that movement is irrelevant to the task (e.g., May & Klatzky, 2000), suggesting that one's immediate position in an environment plays an important role in the maintenance and tracking of object locations.

Current position also plays a role in spatial reasoning. In our example, if instead you were asked how you would reach for the coffee maker if you were standing at the sink, your current position would likely conflict with the to-be-imagined position. This interference between current and imagined positions can affect retrieval of object locations (May, 2004, 2007). When participants learned a spatial layout and made location judgments from imagined headings, response latencies were longer when testing novel orientations in the actual environment than when testing those same orientations remotely. This effect of test environment on imagining novel orientations was attributed to interference from one's current position when trying to imagine space from another perspective (Kelly, Avraamides, & Loomis, 2007; May, 2004, 2007).

One potential model for the difference between testing in a space and testing remotely is that these test contexts rely on two representations (Mou, McNamara, Rump, & Xiao, 2006; Mou, McNamara, Valiquette, & Rump, 2004; Sargent, Dopkins, Philbeck, & Modarres, 2008; Waller & Hodgson, 2006; Wang & Spelke, 2000). When in a space, one has a dynamic representation that tracks where one is located at any given point in time, that is, the representation of one's "current position" from which all immediate actions are executed. This transient representation is believed to be of high fidelity and maintained and updated by continuous perceptual input (visual and/or nonvisual). In addition, for any learned environment, one has a long-term memory representation that can be called upon for spatial reasoning. This long-term representation is believed to be of coarser resolution and is framed in a stable reference system. According to this model, testing within the studied environment relies on the transient representation, and performance is hampered when there is conflict between the participant's current position and the orientation from which reasoning must be done. In contrast, testing remotely depends on the long-term representation, and performance is hampered when there is a conflict between the stored reference frame and the orientation from which reasoning must be done.

Many studies of spatial memory have presumably avoided the interfering biases of one's immediate position in the environment by disorienting participants and moving them to different rooms between study and test (e.g., Easton & Sholl, 1995; Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998; Shelton & McNamara, 1997, 2001a, 2001b, 2004a, 2004b). The assumption has been that once the contact between the observer and the immediate environ-

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ment is disrupted, the transient representation, and therefore the added interference of current position, no longer impacts behavioral performance. In addition, with sufficiently difficult displays, intervening tasks, and/or delays between study and test, there is little chance that participants maintain a working memory representation of the space. According to a dual representation model, this type of remote testing should eliminate one source of orientation dependence (interference from current position) and allow us to study only the effects of the long-term memory's principal reference orientation.

Although this approach appears to be valid on the surface, it assumes dual representations. However, one can posit two sources of orientation dependence without assuming that sensorimotor interference and principal reference orientations are strictly tied to transient and long-term representations, respectively. Indeed, evidence from Kelly et al. (2007) suggests that the sensorimotor interference, thought to be associated with a transient representation, can be invoked during retrieval of a long-term memory representation by introducing perceptual similarity between the learned environment and the testing room. In their study, participants learned an environment in one room and were subsequently tested in a different room that was structurally similar. Participants showed both orientation dependence for the learned orientation and facilitation for their position in the testing room. Novel orientations that were neither the learned view nor the current position relative to the similar room structure showed a cost in retrieval. Given that this was a form of remote testing, these data suggest that interference from current position can interact with long-term memory retrieval even after the transient representation of the to-be-remembered space has been eliminated.

One explanation for Kelly et al.'s (2007) result is a cue-based account: The perceptual similarity between one's current position in the testing environment cues that same position in the learned environment, providing both facilitation for retrieving that orientation and interference for retrieving other orientations. One instantiation of this retrieval cue account is that the current perceptually similar space becomes a proxy for the space retrieved from memory. Conceptually, this would be akin to overlaying the memory for the to-be-remembered space onto the perceptually similar structure of the current testing space. In this version of the cue-based account, the testing room similarity puts the participant conceptually back in the to-be-remembered space (as in the same-room testing conditions) rather than simply serving as a cue to retrieval on particular trials.

To explore this notion of conceptual current position and its role in spatial memory retrieval, we conducted a series of experiments in which the study–test perceptual similarity was kept constant to assess whether the distinction between testing in the same or perceptually similar room and testing in a remote room can be driven by conceptual instructions. We propose that current position is a conceptual state that can interact with long-term memory when it is a position in the relevant space for retrieval (as in the same room or perceptually similar proxy room) or be ignored when it is a position in a space irrelevant to the spatial retrieval (as in the remote testing room). In addition, we explored potential mechanisms for choosing a conceptual position under ambiguous conditions.

In all the experiments presented here, participants were tested in the same room that was used for studying the spatial layout, but we varied whether participants were made explicitly aware of their test position. Despite including the typical disorientation and intervening activities that are meant to ensure long-term memory dependence, simple instructions about the participant's position had pronounced effects on memory retrieval. Moreover, these effects of instruction interacted with whether participants were given an opportunity to update their position while still in the room after encoding. Together, the results speak to the cognitive influences that participate in the way people retrieve spatial information from long-term memory.

Experiment 1

Perceptual similarity between study and test rooms appears to produce sensorimotor interference even after the immediate working memory representation of a space has been disrupted (Kelly et al., 2007). Our hypothesis is that perceptual similarity essentially allows participants to use the test room as a proxy for the learned environment. That is, participants are adopting a current position that conceptually places them back in the space that is being retrieved from memory. To establish the notion of a conceptual current position, we held perceptual similarity constant and varied the instructions participants were given about their position following disorientation and delay. One group was told that it was back in the learned environment, and the other was told that it was to imagine the learned environment. If the effects observed previously were strictly due to structural similarity, then our participants should all experience the same degree of sensorimotor interference, and our instructions should have no effect. However, if current position is a more flexible concept, then our instruction to be in the room should show more sensorimotor interference than our instruction simply to imagine the room. In effect, the instructions should replicate effects due to testing in a space versus testing remotely, even though both groups underwent identical encoding and were actually placed in physically identical test environments.

The interference can be measured by establishing the cost for imagining novel orientations compared with the learned orientation. We expected to see this cost in angular error of pointing, but it can also be seen in latency measures (e.g., Mou, Liu, & McNamara, 2008; Mou et al., 2006; Mou, Zhao, & McNamara, 2007; Roskos-Ewoldsen et al., 1998; Shelton & McNamara, 1997, 2001a, 2004a, 2004b). Throughout the study, all conditions were expected to show such a cost due to the need to transform the space in memory to the imagined orientation, but the magnitude of that cost was expected to be greater in conditions with added sensorimotor interference. In Experiment 1, the learned orientation and the conceptual current position were congruent to allow us to estimate any added cost due to sensorimotor interference when participants were instructed to assume a current position back in the learned environment. These are teased apart in subsequent experiments.

Method

Participants. Twenty-four participants (12 women, 12 men) volunteered in return for extra credit in psychology and cognitive science courses. All participants had normal or corrected-to-normal vision and hearing, were native English speakers, and had

no history of head trauma or neurological disorder by self-report. All participants signed informed consent to participate.

Materials and design. Two configurations based on Shelton and McNamara (1997, 2001a) were assigned seven common objects and placed on the floor of a large room (see, e.g., Figure 1). Nine floor-to-ceiling temporary walls surrounded the display area to create a circular room that was 10 ft (3 m) in diameter, obscuring all corners and doors. Four possible learning positions within the surrounding room were used based on the corners of the obscured rectangular structure, and the display was oriented with one of the eight possible orientations randomly selected as 0°.[1] For each participant, the learning position was arbitrarily labeled 0° for subsequent testing.

For the test, participants were assigned to one of two instructional groups. Both groups were tested in the same room as the learning phase (see Procedures) but were given different instructions about the space. In the *same room* instruction group, the experimenter said, "You are back in the room where you learned those objects." In the *different room* instruction group, the experimenter said, "Imagine that room where you learned those objects." Equal numbers of men and women were randomly assigned to the two instruction conditions.

Two memory tests were used to evaluate the effects of the instructional manipulation. The first test, preliminary blindfolded pointing, required participants to physically point to the objects from the learning position. A simple half-circle protractor was equipped with a pointer (a narrow dowel rod) anchored at the origin to serve as a pointing device. Trials consisted of the verbal label for each of the seven learned objects, presented in random order. The participant was asked to point to the named object as accurately as possible from memory by turning the pointer to the appropriate direction. The angle of the pointer was recorded. The second test consisted of judgments of relative direction (JRDs), frequently used to evaluate effects of orientation (e.g., Shelton & McNamara, 2001a). Each trial consisted of three of the learned objects. The first two established the imagined heading ("Imagine you are at the ball and facing the shoe.") and the third object served as the target ("Point to the book."). Each imagined heading was aligned with one of eight possible orientations ranging from 0° (as defined by the learned orientation) to 315° in 45° increments. Targets were selected to cover four possible pointing ranges defined by dividing the space into four quadrants (front, back, left, and right) with a 15° separation between each quadrant. This allowed us to clearly classify and counterbalance pointing direction to target across orientations. The test comprised eight trials at each orientation (two targets in each pointing direction) for a total of 64 trials. Trials were presented on a computer screen along with a circle and movable line. The participant used the mouse to position the line on the circle to reflect the direction of pointing. Angular error and response latency were recorded.

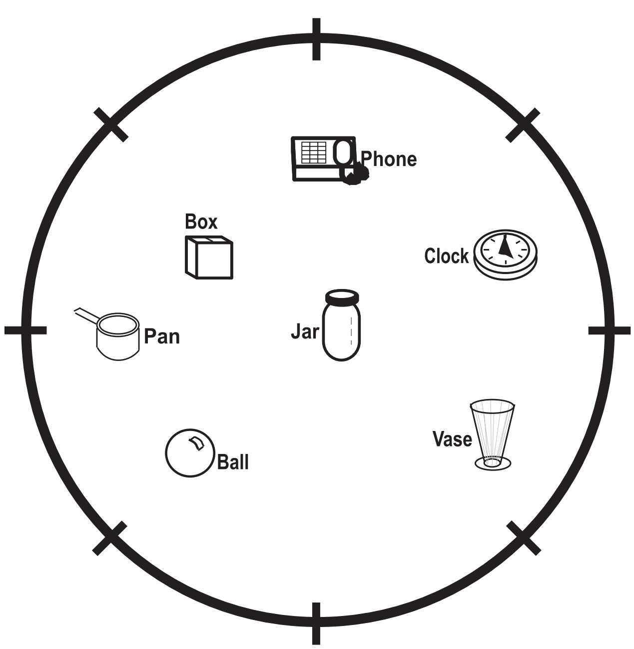

Figure 1. Schematic of one of the object displays used in the study. Tick marks represent the eight possible learning orientations (randomly selected per subject) in the display.

Procedures. All participants completed the same learning phase. To begin, the participant was blindfolded and seated in a chair with casters. The experimenter disoriented the participant by first spinning the chair gently several times and then taking a meandering path into the nine-sided room. Inside the room, the chair was again spun gently before taking a meandering path to the learning position (defined arbitrarily as 0°).[2] The participant was asked to stand at the learning position, and the blindfold was removed. The participant was given 1 min to study the display of objects before the blindfold was replaced. After each 1-min viewing period, the participant was asked to point to all seven objects. This procedure continued until the participant could fluently point to each object correctly (within about 8 in. of the object center) in two consecutive cycles. It took participants from four to eight cycles ($M = 6.2$; no differences due to group or gender) to reach criterion.

Following the learning phase, the participant was seated, disoriented, and wheeled out of the room. Outside the room, the participant was again disoriented and given a 5-min break. For the test, the participant was seated, disoriented again, and then wheeled back into the experimental chamber and disoriented. The lights were turned off and the objects removed from the floor. Up to this point, the two groups underwent identical procedures. The blindfolded participants were then given either the *same room* or *different room* instructions. Following this instruction, the test phase was identical for the two groups.

First, the blindfolded participant stood at the edge of the nine-sided room, holding the pointing device with the flat edge of the protractor against his or her torso. The experimenter listed each of the seven object names in random order, and for each object the participant moved the dial to indicate the direction of the named object. The experimenter recorded the angular response.

[1] We did not expect participants to be aware of the surrounding room, but we did not obscure the ceiling. As a result, we did not want to have learned views aligned with the walls of the room in some cases and not in others, on the basis of known effects of alignment (Shelton & McNamara, 2001a).

[2] Pilot work has indicated that this procedure is sufficient to produce chance performance on localizing the door to the experimental chamber.

Next, the participant was seated in a chair (at the same location as the preliminary blindfolded pointing), and the blindfold was removed. The room remained dark except for the screen of a laptop placed on a small table in front of the participant. The participant was given written instructions on JRDs and six practice trials using buildings on the campus (e.g., "Imagine you are the library and facing the cafeteria. Point to the lacrosse field."). The participant then completed the 64 JRD trials in random order. Following the last test, the participant was given paper with a circle on it and asked to draw a map of the display. The participant was then blindfolded, disoriented, and taken out of the room for debriefing. In the postexperiment debriefing, participants were asked about strategies used during JRDs and their impressions of their location during testing ("What was the relationship between the study and test room?").

Results and Discussion

Maps were first assessed to be certain that all participants had a basic understanding of the object layout. All participant maps were drawn from the learned orientation (0°) and had minimal spatial distortion and no effects due to any of our manipulations.

Preliminary blindfolded pointing from the learning position. Data were first interrogated as signed errors to determine whether there were any systematic biases. In all conditions, the average signed error was close to 0°, suggesting that any differences among conditions were in magnitude and not direction.[3] The mean absolute angular error was then calculated for each participant's pointing (based on the seven pointing judgments). Data were analyzed in a completely randomized analysis of variance (ANOVA) with sex and room instructions as between-subjects factors. Only the effect of room instruction was significant, $F(1, 20) = 10.50$, $p = .004$, $\eta_p^2 = .34$, indicating that the *same room* group ($M = 6.69°$, $SE = 1.3°$) had lower angular error than the *different room* group ($M = 12.66°$, $SE = 1.3°$), suggesting that the instruction about location had a substantial effect on the retrieval of the object locations. (For sex and sex by room instruction, $p = .63$ and .18, respectively.)

JRDs. In this and all subsequent studies, response latency effects showed patterns identical to those observed in angular error. In most cases, these effects were not significant because of the noisy nature of long response latencies in these tasks, but their similarity to the angular error data is consistent with the results of numerous previous studies (e.g., Easton & Sholl, 1995; Mou & McNamara, 2002; Mou et al., 2004; Roskos-Ewoldsen et al., 1998; Shelton & McNamara, 1997, 2001a, 2001b, 2004b; Shelton & Pippitt, 2007). Indeed, JRDs can be run with different constraints to force the effects to be stronger in one measure or the other, but they lead to the same conclusions about orientation dependence and interference.

Angular error data were first interrogated as signed errors to determine whether there were any systematic biases. In all conditions, the average signed error was close to 0°, suggesting that any differences among conditions were in magnitude and not direction. Mean absolute angular errors were then calculated as a function of orientation and pointing direction for each participant. Angular errors were analyzed in an ANOVA with sex and room instruction as between-subjects factors and orientation and pointing direction as within-subject factors. Analyses for all within-subject components were corrected for nonsphericity with Geisser–Greenhouse corrected probabilities.

As expected from previous studies (e.g., Shelton & McNamara, 1997, 2001a), the main effect of pointing direction was significant, $F(3, 60) = 13.30$, $p < .001$, $\eta_p^2 = .40$, with more accurate pointing to targets in the front compared with the sides, $F(1, 60) = 12.61$, $p < .001$, and more accurate for the sides than the back, $F(1, 60) = 13.81$, $p < .001$. Pointing direction did not interact with any of the other effects or compromise any of the conclusions.

In terms of room instruction and orientation, the main effect of room instruction was significant, $F(1, 20) = 15.53$, $p = .001$, $\eta_p^2 = .44$, with the *same room* group ($M = 33.2°$) performance worse than that of the *different room* group ($M = 24.8°$). The main effect of orientation was also significant, $F(7, 140) = 65.93$, $p < .001$, $\eta_p^2 = .77$, reflecting best performance at the learned orientation (0°) compared with other orientations, $F(1, 24) = 116.6$, $p < .001$. Most important, the interaction of orientation and room instruction was significant, $F(7, 140) = 10.48$, $p < .001$, $\eta_p^2 = .34$. As seen in Figure 2, the difference between the learned orientation (0°) and all novel orientations was larger for the group that received the *same room* instruction, $F(1, 24) = 10.97$, $p = .003$, suggesting that telling participants that they are back in the learning environment increased the difficulty or interference associated with imagining novel orientations. Moreover, this cost for taking novel orientations in JRDs was negatively correlated with the performance on the initial blindfolded pointing task for the entire group, $r(23) = -.74$, as well as for the two instruction groups separately, $r(11) = -.60$ and $-.61$, for *same room* and *different room* instructions, respectively. That is, those who were most accurate with the learned view incurred greater cost for novel orientations, providing support for the interference theory at the individual level.

The results of Experiment 1 revealed a striking effect of the room instructions manipulation. First, it revealed better performance on the test from the learning position when participants were told that they were back in the room. However, this advantage was complemented by a disadvantage for having to subsequently imagine novel views in JRDs. This added cost for novel views is akin to the effects observed by May (2007), suggesting interference between one's immediate perspective and a to-be-imagined perspective. Unlike May's participants, however, all our participants were disoriented before testing and performed the test in the same physical environment. Moreover, it was not evident that participants in the *different room* group fully believed it was a different room; indeed, five of the participants in the *different room* group actually inquired about whether the testing room was the learning environment when the blindfold was removed for the JRD task. In these cases, they were given the ambiguous response "We have several lab rooms." In postexperiment interviews, all participants indicated that they suspected the test room was actu-

[3] Signed error and absolute error capture different information. Systematic signed errors would reflect consistent but distorted representations. When no systematic distortions are revealed, absolute error captures the imprecision of judgments. Distinguishing sources of errors has been largely unexplored, but we have recent evidence to support claims that the patterns of error in JRDs capture imprecision or noise rather than any consistent distortion within or between individuals (Marchette, Trossett, Priebe, Marchette, & Shelton, 2010).

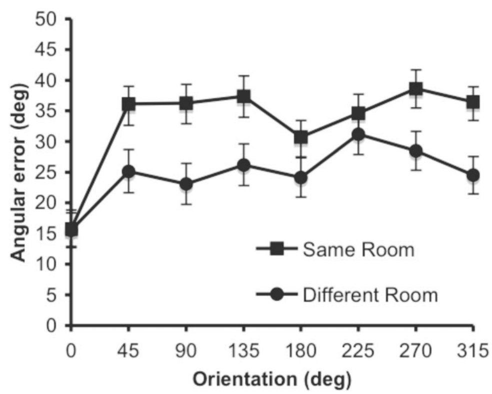

Figure 2. Angular error in judgments of relative direction as a function of room instruction and orientation of the imagined headings in Experiment 1. Error bars reflect ±1 *SEM*. deg = degrees.

ally the study room when asked about the relationship between the study room and the test room. More specifically, all participants said some variant of "it looked like the same room," and none expressed disagreement when told that it was actually the same room. Regardless, there was a clear effect of the instructions, suggesting that access to and manipulation of the long-term memory representation was interacting with the way we motivated them to think about the space (being there vs. imagining the space). In other words, after identical encoding procedures, in perceptually identical testing conditions, the type of instruction we gave determined the strength of the observed orientation dependence (i.e., interference), even if the instruction may not have been particularly compelling. (Of course, these interviews are done in hindsight, and the question about the study and test rooms alone might motivate certain answers, regardless of the participants' actual experiences.)

Experiment 1 raised a number of issues for our interpretations of memory retrieval, however. The first important concern is the use of a preliminary memory task in both groups in Experiment 1. The preliminary blindfolded pointing likely anchored participants to the learning position, establishing a potential "current position" in the space. Although this did not eliminate the effect of instructions, it does raise the issue of how current position in the *same room* condition would be interpreted if participants were not given this opportunity to clearly reestablish the learning position. In Experiments 2 and 3a, this preliminary blindfolded pointing was eliminated to avoid the possible influence of taking this viewpoint so that we could better assess the factors affecting how apparent current position might interact with long-term memory retrieval. We bring it back in Experiment 3b as an added control.

A second important question is that of how long-term memory might be used to establish a meaningful current position. When the participant was returned to the room for the memory test, the cues were intentionally ambiguous with respect to the participant's actual position, yet we see effects of interference consistent with an apparent adoption of the learned orientation when *same room* instructions were used. One clear theoretical model for establishing a current position in an ambiguous test setting is that participants adopt a current position corresponding to the preferred orientation in long-term memory. However, in the *same room* condition of Experiment 1, we confounded the learned (and preferred) orientation with the last known position in the study room. Studies of remote testing following multiple views have clearly demonstrated that the preferred orientation need not be the last known position when multiple learned orientations are available (Shelton & McNamara, 2001a). To test the whether learned orientation and last known position might have different roles in the memory representation, we can dissociate them by asking participants to walk without vision to another position at the end of the encoding phase. Experiments 2 and 3a were designed to weigh in on the role of last known position by evaluating the effects of this nonvisual updating on JRD performance.

Experiment 2

In Experiment 1, the participants appeared to use the instructions as a cue for how to retrieve spatial information about a learned array, with different results for being in the room versus imagining the room. In particular, we anticipated stronger orientation dependence, as evidenced by a greater cost for novel views, in the *same room* group compared with the *different room* group, consistent with using one's current position in the former more than the latter. To lay the groundwork for testing whether nonvisual updating has differential effects as a function of the relevance of current position, we first established its effects on JRD performance from memory when participants were actually in the same space, without disorientation or instruction.

Method

Participants. Sixteen participants (eight women, eight men) volunteered in return for extra credit in psychology and cognitive science courses. All participants had normal or corrected-to-normal vision and hearing, were native English speakers, and had no history of head trauma or neurological disorder by self-report. All participants signed informed consent to participate.

Materials, design, and procedure. The materials were the same as in Experiment 1 except that the preliminary blindfolded pointing from the learning position was eliminated to avoid clearly establishing a position before completing the JRD task. Equal numbers of men and women were randomly assigned to either an *update* or *no update* group.

The learning phase was conducted as in Experiment 1 until the participants reached the learning criterion. It took participants from four to seven cycles (M = 5.4; no differences due to group or gender) to reach criterion. In the *no update* group, the blindfolded participant put on padded headphones, stood still for 30 s, and was then seated in a chair at the learning position. In the *update* group, the blindfolded participant was asked to place his or her right hand on the wall of the nine-sided room, and the experimenter said, "We will now walk to the opposite side of the display." The experimenter guided the participant along the wall to the position 180° away from the learning position. The participant then turned to face the display, put on padded headphones, and was seated in a chair at that position. With the blindfolded participant seated, the experimenter quickly removed objects from the floor of the room, shut off the lights, and set up a table and laptop for doing JRDs. All participants completed the practice trials and 64 JRD trials in random order. Map drawing was completed outside the testing

room. (Postexperiment interviews asked only about the difficulty and strategies of JRDs because there was no room instruction manipulation.)

Results and Discussion

All participant maps were drawn from the learned orientation (0°) and had minimal spatial distortion and no effects due to any of our manipulations. Previous studies have shown that map-drawing orientation often corresponds to the preferred orientation in JRDs (e.g., Shelton & McNamara, 1997, 2001a, 2004a), suggesting that updating did not affect the selection of a preferred orientation.

After establishing that there were no systematic biases in signed error, absolute angular errors in JRDs were analyzed in an ANOVA with sex and update (*update* or *no update*) as between-subjects factors and orientation and pointing direction as within-subject factors. The main effect of group was significant, $F(1, 12) = 9.20$, $p = .01$, $\eta_p^2 = .43$, indicating that the *no update* group ($M = 33.7°$) was more accurate than the *update* group ($M = 42.1°$). In addition, the main effect of orientation was significant, $F(7, 84) = 21.70$, $p < .001$, $\eta_p^2 = .64$, as was the Group × Orientation interaction, $F(7, 84) = 14.51$, $p < .001$, $\eta_p^2 = .55$. As shown in Figure 3, the main effect and interaction were captured by the presence of a preferred orientation in each group and the difference between them. The *no update* group showed the typical effect with more accurate performance at the learned orientation (0°) than at novel orientations, $F(1, 12) = 11.39$, $p = .006$, whereas the *update* group showed more accurate performance at the current (unseen) position (180°) compared with all other novel views and the learned view, $F(1, 12) = 16.46$, $p = .002$. In this group, the learned orientation (0°) was not different from the other novel views, $F(1, 12) = 1.76$, $p = .21$. The interaction contrast for the groups comparing 0° and 180° orientations was significant, $F(1, 12) = 6.30$, $p = .03$, supporting this switch in preferred orientations. Notably, this preferred orientation shift was not evident in map drawing. This inconsistency may be due to the fact that map drawing was tested outside the study room in all cases, thus relying on the long-term representation without interference from expected immediate position. We return to this question in the General Discussion.

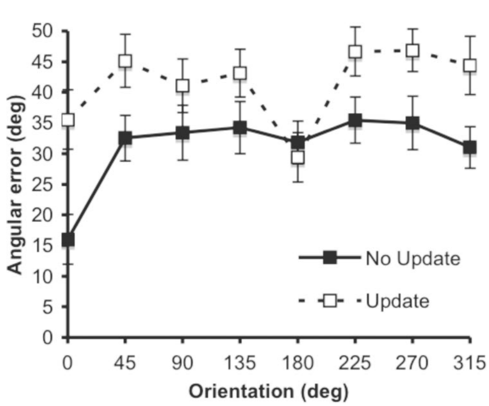

Figure 3. Angular error in judgments of relative direction as a function of updating condition and orientation of the imagined headings in Experiment 2. Error bars reflect ±1 *SEM*. deg = degrees.

Together, these results suggest that current position has a pronounced effect on memory retrieval. Nonvisual updating appeared to motivate participants to retrieve the spatial array from the updated position, even though the object display was never seen from this orientation. When participants were asked to imagine the original orientation, there was a cost in accuracy as if the learned view were novel relative to the updated orientation, suggesting that current position interfered with retrieval of the information in the learned orientation. This strong support for the dominance of the current position when tested in the study space lays the foundation for exploring the interaction of this robust influence of current position with the manipulation of testing conditions after disorientation and delay.

Experiment 3a

In Experiment 1, we argued that participants were compelled to adopt a current position that was essentially within the to-be-tested space when given the *same room* condition. Under these ambiguous testing conditions, they appeared to rely heavily on their learned orientation to establish current position. However, the learned position was also confounded with their last known position in the to-be-remembered space. In Experiment 2, we established that participants indeed used their known current position when kept in the same room for testing, even if that current position was suboptimal. In Experiment 3a, we asked whether the last known position might play a role in retrieval by investigating whether nonvisual updating prior to disorientation and delay affects how participants establish their current position under ambiguous testing conditions. That is, if we update participants prior to leaving the encoding phase of the experiment, is there any residual effect of that updating when they are brought back to the room and given the *same room* versus *different room* instructions? Therefore, Experiment 3a combined the room instruction manipulation from Experiment 1 with the updating conditions of Experiment 2 to ask how blindfolded updating during encoding might affect access to long-term memory representations.

Following the same procedures as Experiment 2, participants were in either the *update* or *no update* group during encoding. Following disorientation, all participants were then brought back into the room and given either the *same room* or *different room* instructions. The hypotheses can then be characterized according to expectations about preferred orientation and interference costs. First, the *no update* groups served as a direct replication of the room instruction manipulation from Experiment 1. Therefore, we expected these conditions to show a clear preferred orientation corresponding to the learned view, with the *same room* group incurring a greater cost than the *different room* group for taking nonpreferred orientations. Second, the two *update* groups were treated identically during the encoding phase and were expected to have the same preferred orientation in long-term memory. On the basis of previous studies, the learned view should provide a better reference than the updated position because the updated position is never actually viewed. As such, we expected that the *update–different room* group would show a preferred orientation corresponding to the learned view and appear identical to the *no update–different room* group. Therefore, the key question was about the preferred orientation and associated costs in the *update–same room* group. If the *same room* instructions invoked a current

position that corresponds to the preferred orientation in long-term memory, then we would expect this group to show the same effect as the *no update–same room* group. In other words, there would be no effect of updating and no interaction with room instruction. However, if establishing a position takes into account the last known position, we might expect performance in the *update–same room* group to look like the *update* condition in Experiment 2, with a preferred orientation, and thus an apparent current position, at the updated view (180°). This would provide evidence for a flexible long-term representation that includes information about last known position.

Method

Participants. Thirty-two participants (16 women, 16 men) volunteered in return for extra credit in psychology and cognitive science courses. All participants had normal or corrected-to-normal vision and hearing, were native English speakers, and had no history of head trauma or neurological disorder by self-report. All participants signed informed consent to participate.

Materials, design, and procedure. The materials were the same as in Experiment 1 except that only the JRD test was administered to avoid clearly establishing a position before retrieval. Equal numbers of men and women were randomly assigned to one of four conditions based on the factorial combination of updating (*update* or *no update*) and room instructions (*same room* or *different room*). Procedures were identical to those in Experiment 2 until the end of the encoding session, including the *update* and *no update* procedures. It is critical to note that for the two groups that received updating (*update–same room* and *update–different room*), the updating (a) took place during the encoding phase, (b) was directed specifically ("We will now walk to the opposite side of the display."), and (c) involved actual physical walking. These groups were therefore treated identically in all respects up to the point of retrieval (several minutes after encoding) when given the *same room* or *different room* instructions. Participants' cycles to reach criterion ranged from four to nine cycles (M = 6.4; no differences due to group, room instruction, or gender). After the updating manipulation, participants were seated in the wheelchair, disoriented, removed from the room, and disoriented again, as in Experiment 1. Following a short break, they were returned to the room and given either the *same room* or *different room* instructions as in Experiment 1. Participants were not given any information about their particular position in the room for either instruction, and they were not asked to do the pointing from the learned position. Instead they were seated immediately in the darkened room to do the JRD task. All participants completed the practice trials and 64 JRD trials in random order. Map drawing was completed outside the testing room. As in Experiment 1, postexperiment interviews asked about strategies used during JRDs and participants' impressions of their location during testing ("What was the relationship between the study and test room?").

Results and Discussion

All participant maps were drawn from the learned orientation (0°) and had minimal spatial distortion and no effects due to any of our manipulations.

After establishing that there were no systematic biases in signed error, absolute angular error data were analyzed in an ANOVA with sex, update (*update* or *no update*), and room instruction (*same* or *different*) as between-subjects factors and orientation and pointing direction as within-subject factors. All within-subject effects, interactions, and contrasts were corrected for nonspherical data. The most striking result, shown in Figure 4, is the significant interaction of room instruction, updating condition, and orientation, $F(7, 168) = 6.08$, $p < .001$, $\eta_p^2 = .20$, resulting largely from differences in the apparent preferred orientation. Simple effect contrasts were used to assess the preferred orientation by testing whether novel orientations differed from the learned orientation (0°) in each of the groups. This contrast was significant for the *no update–same room* group, $F(1, 24) = 41.26$, $p < .001$; the *no update–different room* group, $F(1, 24) = 10.64$, $p = .003$; and the *update–different room* group, $F(1, 24) = 11.01$, $p = .003$; but it was not significant (or marginally so at best) in the *update–same room* group, $F(1, 24) = 2.97$, $p = .10$. Alternatively, a simple effect contrast for 180° (the orientation to which participants updated) compared with all other orientations was significant for the *update–same room* group, $F(1, 24) = 30.53$, $p < .001$, but not for any remaining groups (Fs < 1). Notably, the *update–same room* group did show an advantage for 0° headings relative to all novel orientation excluding 180°, $F(1, 24) = 7.14$, $p = .013$, suggesting that 0° was more accurate than true novel views. However, 0° was less accurate than the apparent preferred orientation at 180°, $F(1, 24) = 6.37$, $p = .02$. In all other groups, 0° was significantly more accurate than 180° ($ps < .05$). This was captured by the significant interaction contrast for *same room* versus *different room* by *update* versus *no update* by 0° versus 180°, $F(1, 24) = 9.24$, $p = .006$.

Overall, there was a main effect of room instruction with the two *same room* instruction groups (M = 34.5°) performing worse than the two *different room* instruction groups (M = 24.4°), $F(1, 24) = 88.89$, $p < .001$, $\eta_p^2 = .79$, as well as a significant interaction of room instruction by updating condition, $F(1, 24) = 7.53$, $p = .01$, $\eta_p^2 = .24$. These effects appear to be due to two key factors. First, in the update group with the *same room* instruction, we observed

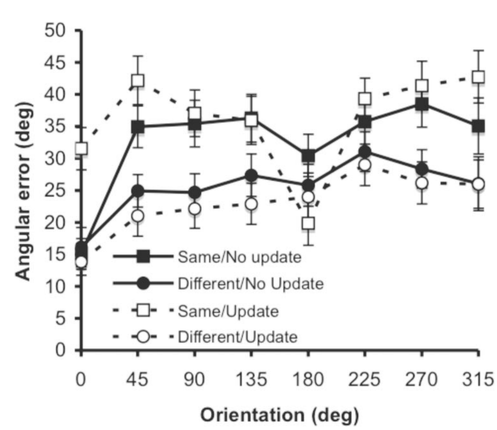

Figure 4. Angular error in judgments of relative direction as a function of room instruction, updating condition, and orientation of the imagined heading in Experiment 3a. Error bars reflect ±1 *SEM*. deg = degrees.

an overall elevation in the angular error, similar to that observed in Experiment 2. For example, at the apparent preferred orientation of 180°, angular error was 5° higher than the average overall error of the other three groups. More substantially, there appears to be a bigger cost for nonpreferred orientations in the *same room* instruction groups than in the different room instruction groups as observed in Experiment 1. To assess this latter effect, the data were redefined in terms of cost (nonpreferred–preferred) for the four groups and subjected to an ANOVA with sex, update group, and room instruction as between-subjects factors. Only the effect of room instruction was significant, $F(1, 24) = 25.21$, $p < .001$, $\eta_p^2 = .51$, with the *same room* instructions producing a much greater cost ($M = 19.7°$) than the *different room* instructions ($M = 10.8°$). No other effects or interactions approached significance ($ps > .30$).

Together, these results suggest that the influence of instructions may result in very specific expectations of one's current position. In particular, under *same room* instructions, our participants appeared to perform as if they had been returned to their last known position in the space prior to disorientation. This expectation amounted to a perceived current position at the site (or at least the orientation) of learning in the *no update–same room* group, whereas it amounted to a perceived current position at the termination point of blindfolded updating in the *update–same room* group. To our knowledge, this is the first demonstration of such a potent effect of updating on retrieval of spatial information when there is both delay and disorientation between the updating and the retrieval. In contrast, the physical updating at the end of the encoding phase had no effect on subsequent retrieval in the *different room* conditions, suggesting that participants were accessing their long-term representation without any particular expectation or effect of current position in the test space. That is, they demonstrated the classic preferred orientation effect seen when participants are tested remotely, with or without blindfolded updating at the end of the encoding phase. This instruction by updating interaction provides an even stronger case for conceptual influences on the perception of current position. In addition, it suggests that the long-term memory representation can have both stable properties such as preferred orientation and malleable features reflecting recent experiences such as last known position. These malleable features of long-term memory have grounding in anecdotal accounts and are discussed in more detail in the General Discussion.

Experiment 3b

In Experiment 3a, we observed a preferred orientation for imagined headings at the learned orientation and at the updated orientation for the *no update–same room* and *update–same room* groups, respectively. Both these groups also showed an increased cost for novel orientations, consistent with sensorimotor interference due to current position in the to-be-remembered space. We argue that these participants were adopting their last known position or last salient position in the space when the location within that room was ambiguous. As this is one of the novel contributions of this work, it is important to show that disambiguating location can eliminate the effects of last known position. After several attempts that proved confusing for participants, we returned to the simple case of having a preliminary blindfolded pointing task before the participant ever viewed the testing room. By asking participants to point to the objects from a specific position (the learning position), we expected to effectively identify a location in the room for them. All participants underwent updating at the end of encoding prior to disorientation, and we again manipulated whether they were given the *same room* or *different room* instructions (i.e., identical to the *update–same room* and *update–different room* groups from Experiment 3a). We expected that this procedure would conceptually return participants to the learning position upon reentry to the room, specifically in the *same room* instruction group. That is, by asking them to point from the learning position, the location in the testing room would be disambiguated before they had a chance to see the actual space. For the *same room* groups, this should eliminate the use of the 180° orientation as the preferred orientation in JRDs. Therefore, the results were expected to show a preferred orientation at the learned orientation (0°) in the *same room* and *different room* groups but also greater cost in accuracy for novel orientations in the *same room* group than in the *different room* group. In effect, we expected to replicate Experiment 1 even though all participants did the physical nonvisual updating during the encoding phase.

Method

Participants. Twelve participants (eight women, four men) volunteered in return for extra credit in psychology and cognitive science courses or monetary compensation. All participants had normal or corrected-to-normal vision and hearing, were native English speakers, and had no history of head trauma or neurological disorder by self-report. All participants signed informed consent to participate.

Materials, design, and procedure. The materials were the same as in Experiment 1. Participants were randomly assigned to one of the room instructions (*same room* or *different room*), with the constraint that four women and two men be assigned to each group.[4]

Procedures were identical to the *update* conditions in Experiment 3a, with both groups learning from 0° and updating physically to 180° prior to disorientation. Participants' encoding cycles to reach criterion ranged from four to nine cycles ($M = 6.4$; no differences due to group, room instruction, or gender). After the updating manipulation, participants were seated in the wheelchair, disoriented, removed from the room, and disoriented again, as in Experiment 1. Following a short break, they were returned to the room and given either the *same room* or *different room* instructions as in Experiment 1. Before removing the blindfold, all participants did the preliminary pointing from the learned orientation using the same procedures as in Experiment 1. All participants then completed the practice trials and 64 JRD trials in random order. Map drawing was completed outside the testing room. As in Experiment 1, postexperiment interviews asked about strategies used during JRDs and participants' impressions of their location during testing ("What was the relationship between the study and test room?").

[4] As this was a control experiment, we limited the number of participants. We also had substantial difficulty recruiting male participants. Therefore, we choose to balance the groups by sex even though the sexes were not equally represented. This factor did not affect any of the previous experiments, so it was not considered critical.

Results and Discussion

All participant maps were drawn from the learned orientation (0°) and had minimal spatial distortion and no effects due to any of our manipulations.

Signed errors from the preliminary blindfolded pointing were first interrogated to determine whether there were any systematic biases. In all conditions, the average signed error was close to 0°, suggesting that any differences among conditions were in magnitude and not direction. The mean absolute angular error was then calculated for each participant's pointing (based on the seven pointing judgments). As in Experiment 1, angular error was lower in the *same room* group (M = 7.45°, SE = 1.39°) than in the *different room* group (M = 13.12°, SE = 2.15°), $t(10) = 2.213$, $p = .05$. This replication suggests that the instructions produced different conceptual conditions for pointing. Moreover, updating during encoding did not appear to eliminate the effect of instructions.

For JRDs, after establishing that there were no systematic biases in signed error, absolute angular error data were analyzed in an ANOVA with room instruction (*same* or *different*) as a between-subjects factor and orientation and pointing direction as within-subject factors. First, the main effect of group was significant, $F(1, 10) = 5.27$, $p = .04$, $\eta_p^2 = .35$, with greater angular error for the *same room* group (M = 31.30°) than for the *different room* group (M = 24.81°). Second, the main effect of orientation was significant, $F(7, 70) = 42.95$, $p < .001$, $\eta_p^2 = .81$, with the majority of this effect (92% of the effect variance) captured by the difference between the 0° orientation and all other orientations, $F(1, 10) = 37.09$, $p < .001$. As in all previous experiments, the interaction of group with orientation was significant, $F(7, 70) = 4.17$, $p = .013$, $\eta_p^2 = .29$, but the critical question was in how the patterns differed. The participants in these groups were treated the same way as the two update groups in Experiment 3a until the first test of preliminary blindfolded pointing. Without preliminary pointing, the *same room* group showed a preferred orientation at the updated position (180°). If this preliminary test essentially returned participants to the learned orientation, then we expect that preferred orientation would be at the learned orientation (0°) and not at the updated position (180°). As shown in Figure 5, the preferred orientation for both groups appears to be the learned view (0°). This was supported by simple effect contrasts for each group, with headings at the 0° orientation showing better performance than all other orientations, $F(1, 10) = 25.84$ and 12.45 for *same room* and *different room* groups, respectively. To test the question of cost, the data were redefined in terms of cost (nonpreferred–preferred) for the two groups. The results revealed a larger cost for taking nonpreferred orientations in the *same room* group (M = 20.27°) than in the *different room* group (M = 14.07°), $t(10) = 3.75$, $p = .004$, replicating the added cost that we attribute to added sensorimotor interference from current position.

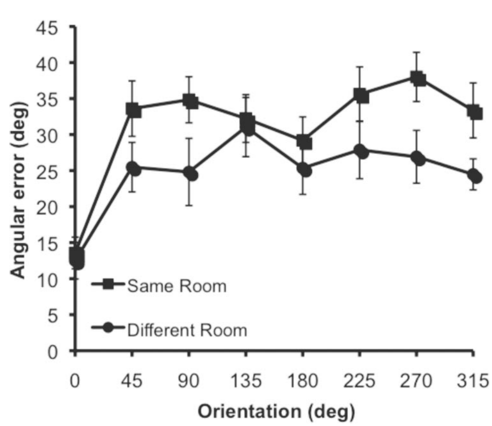

Figure 5. Angular error in judgments of relative direction as a function of room instruction and orientation of the imagined heading in Experiment 3b. Error bars reflect ±1 *SEM*. deg = degrees.

In this case, the results of procedures that proved difficult or confusing also bear on the interpretation of the data in interesting ways. In particular, there were several attempts to include the preliminary pointing task following updating. First, we attempted an ambiguous retrieval by simply stating, "Please point to each of the objects." When this instruction was used with no updating, there was an apparent assumption that we were asking for the locations from the learned position. One of the four participants needed clarification, asking, "You mean from where I saw it?" Participants in the update conditions reacted immediately to this question by universally asking, "From where?" No amount of coaxing could convince them simply to assume some position. If pressed, they would say, for example, "Well, then I will just do it from the view I saw," or they would simply point at random or to the center. This simple instruction was abandoned because it lacked control and frustrated participants. We tried the alternative of asking participants to point from the last position they had in the room, but again, we found that making the instruction explicit confused participants. Comments included "But I did not see it from there" and "You mean the last thing I saw?" Again, the lack of control motivated us to abandon this method as well. Together, these results suggest that although we can conceptually drive participants to assume certain locations (in or out of the room) and even particular locations (at the learning position or last known location), these efforts are hampered when we explicitly draw participants' attention to their location.

More generally, these results provide three important controls for interpreting the previous results. First, they replicate the advantage for the *same room* over *different room* groups in the pointing from the learned view. Again, this cannot be attributed to perceptual cues because they were blindfolded (and even if they had not been, the testing room was identical in all conditions). Second, we again replicated the increased cost for novel views in JRDs for *same room* versus *different room* conditions as in Experiments 1 and 3, suggesting that this is a robust effect of a seemingly simple instruction with or without a preliminary pointing task. Third, these results suggest that the updating effects in Experiment 3a on the JRD task were driven by a need to establish a current position when given the same room instructions in an ambiguous testing situation. It is important to note that the participants in the *update* conditions of Experiments 3 and 3b were treated identically until the preliminary pointing task began. Therefore, any differences must be due to the introduction of that additional task. In the ambiguous case of Experiment 3a, participants appeared to adopt the last known or salient position. When we eliminated the ambiguity by including a preliminary pointing task in Experiment 3b, the last known position based on updating was no longer facilitated, and all orientation and interference effects came from the learned orientation. Clearly, the increased error for novel orientations in the *same room* group still supports the idea that instructions introduced interference from current position, but the use

of the pointing task from the learned position disambiguated current position for retrieval.

General Discussion

Previous studies have shown a greater cost for imagining novel perspectives when tested within the learned environment than when tested remotely (Kelly et al., 2007; May, 2004, 2007). One clear explanation for these effects lies in whether one's current position is having an influence on retrieval—presumably in the form of sensorimotor interference. In the same environment, one's current position is a position in the relevant to-be-remembered space, whereas in a remote environment, one's current position is in a space irrelevant to the spatial retrieval. Kelly et al. (2007) further demonstrated that this sensorimotor interference could be induced by visual and spatial similarity between the learning and testing rooms. To elaborate on possible mechanisms by which a perceptually similar room might exert an effect akin to the actual room, we propose a framework that relies on adopting a conceptual current position. By this account, sensorimotor interference will occur if elements of the testing situation provide sufficient information for the current position to be perceived as a position within the relevant to-be-remembered space. In the Kelly et al. study, this perceptual similarity invoked participants to treat the test space as the relevant to-be-remembered space. In the present study, we took this further by demonstrating the same effect based on a purely conceptual manipulation when perceptual similarity was held constant. In this case, we biased participants to use the current position by actually placing them back in the study space, but we were able to manipulate the degree to which the current position affected their memory retrieval through instructions.

The use of the room instructions allowed us to test participants in the same environment while attempting to alter the way they were thinking about their own current position. In Experiment 1, this manipulation had three complementary effects. First, telling participants that they were back in the learning environment provided an advantage over asking them to imagine the environment on a simple test of pointing to the objects from the learned viewpoint. This preliminary blindfolded pointing was essentially a repetition of the learning criterion test used during encoding, suggesting that even though all participants had reached the same criterion and were treated identically up to the point of blindfolded reentry, the instructions immediately preceding retrieval impacted the precision of memory access. This advantage may be due to facilitation of both orientation (long-term memory preferred orientation) and specific location within that orientation because the learning position captures both a specific orientation (or vector) and a specific viewpoint.

Second, when testing memory with JRDs, the differences at the learned orientation (0°) disappeared. This would be consistent with the fact that the preliminary blindfolded pointing was from both the learned orientation and the learned position. Although previous studies have shown that imagined translations in space are less costly than imagined changes in orientation (e.g., Easton & Sholl, 1995; Klatzky, Loomis, Beall, Chance, & Golledge, 1998), the ability to use one's current orientation and position might give added facilitation to pointing from the learned position. However, for JRDS, the specific heading on each trial uses different positions (i.e., requires translations) such that only the specific orientation can have a direct influence.

Third, the same participants who had better accuracy on the preliminary blindfolded pointing incurred a greater cost for taking nonpreferred orientations. Even though the groups showed equivalent performance at the preferred orientation in JRDs, the participants given the *same room* instruction had more errors on nonpreferred orientations. This cost can be interpreted as showing the same interference that was shown in previous studies, but the critical point is that it is specific to the group of participants who were told that they were back in the room. In the framework we are suggesting, the *same room* instruction was sufficient to indicate that current position was a position in the relevant to-be-remembered space, allowing it to exert its influence in the form of added sensorimotor interference.

We considered whether the added cost for the *same room* group was attributable to a bias from preliminary blindfolded pointing; that is, the blindfolded pointing really established a current position more strongly for the *same room* instruction group than for the *different room* group. However, the *no update* groups in Experiment 3a provided a direct replication of this elevated cost in JRDs without the potential bias of the preliminary blindfolded pointing. Taken together, these results suggest that instructions about one's position can impact how one incorporates current position into the reasoning required during retrieval.

The effects of updating further substantiate these claims. In Experiment 2, we established that participants in a space used their current position as a basis from which to do reasoning for the JRDs, even when they had not seen the display from that current position. That is, the group that did nonvisual updating showed an advantage for the updated orientation when tested immediately from that position. Notably, they did so at a cost to overall accuracy. In Experiment 3a, we tested how strongly this updating affected retrieval by introducing a delay and disorientation after the encoding and updating. The results were surprising and intriguing. Updating affected subsequent long-term retrieval but only when participants were told that they were back in the room. In the memory retrieval performance of the *update–different room* group, there was no discernible behavioral evidence that these participants had experienced any updating during encoding. However, in the *update–same room* group, which received identical treatment up to the point of instruction, the preferred orientation switched to the unseen updated position. One way to interpret these results is that the *update* groups had established a long-term representation that was referenced to the learned orientation just like the other groups (given that they were treated the same way up to the point of testing). However, at the time of retrieval, being told that they were back in the room induced the participants to mentally return to their last known position—the updated position 180° away from the learned orientation. As in the *update* group of Experiment 2, this use of the updated position appeared to incur an overall cost in accuracy in addition to the elevated cost for nonpreferred versus preferred orientations.

The impact of the updating may be surprising given that previous research on updating has suggested that our *update* groups should not have been able to use their updated position (Mou et al., 2004). However, we used a much more forceful updating procedure than in typical studies; we told participants the target of their updating in all cases ("We will now walk to the opposite side of the room."). Therefore, it is unlikely that any form of updating during encoding would have the same consequences. Indeed, Waller and Hodgson (2006) have shown that minimal blindfolded updating is sufficient to

disrupt knowledge of current position. Instead, we are arguing that when you have a recognizable last known position, it can be used to disambiguate the testing conditions.

To our knowledge, this is the first clear example in which effects of one's current position were driven solely by conceptual instruction. The perceptual conditions were identical, controlling for perceptual similarity (Kelly et al., 2007), yet the advantages and disadvantages associated with the instructions about the test environment (same or different from study) were robust. Remarkably, these results did not appear to require strong conviction about one's actual position. Although our instructions were intended to motivate participants to believe that they either were or were not in the original study room, participants did not appear to be completely convinced, particularly in the *different room* instruction groups. Despite some participants' suspicions that they were actually in the same room rather than a different room, they interrogated their spatial memory differently from participants who were told that they were in the room.

One suggestion is that the instructions heightened attention to immediate surroundings in the *same room* compared with the *different room* groups. Although attention may be key, there are two clear challenges to a pure visual selective attention account. First, the room was circular with no objects available to provide clear perceptual cues to location within the room. Even with a partially visible room, there was virtually no cue that would consistently support returning to one's learned or updated position, even if one were attending more. Indeed, there was very little information available to identify any specific orientations during testing. Second, the preliminary blindfolded pointing in Experiment 1 was completed before the participant had any opportunity to see the testing position. On the basis of these arguments, it is likely that the weight given to one's current position rather than any direct perception of a position differed as a function of instruction.

Our alternative interpretation is that our instructions altered the degree to which the participants perceived their current position as being within the relevant to-be-remembered space. If participants are tested in a remote testing room different from the study room, current position exists in an irrelevant space and can be disengaged from the memory retrieval processes. Any cost associated with retrieval is attributed to reconciling the preferred orientation in long-term memory with the to-be-remembered orientation. If participants are in the same room during study and test, the current position is in the relevant to-be-remembered space. In this context, the sensorimotor interference from one's current position exerts a strong influence, increasing the orientation dependence. We observed this effect in Experiment 2, in which participants were tested in the room. Participants in the *update* group appeared to rely on their current unseen position as the point of reference for reasoning, even though it was not optimal for memory. If participants are tested in a structurally similar room (e.g., Kelly et al., 2007), the similarity may allow that space to become a proxy for the to-be-remembered space, again producing a reliance on current position. Finally, in an ambiguous situation, we can use instructions to manipulate the relevance of the current position. In this case, we used a subtle manipulation ("You are in the room . . ." vs. "Imagine the room . . .") to produce a robust, replicable effect. By telling participants that they were back in the study room, they appeared to strengthen their reliance on current position, incurring a benefit for the specific learned position (preliminary blindfolded pointing in Experiments 1 and 3b) and greater orientation dependence (JRDs in all experiments).

For the dual representation model, where do these results leave us? One could argue that our results support a flexible shifting between transient and long-term representations (Burgess, 2006; Waller & Hodgson, 2006). For example, Waller and Hodson (2006) demonstrated that the interference from current position could be disrupted, even when testing in the same room as learning, if participants are minimally disoriented by an oblique body rotation as small as 135°. However, it is less clear that this flexible shifting can account for effects of current position that occur after the transient representation has been disrupted. In both the Kelly et al. (2007) study and the current study (Experiments 1 and 3a), any transient representation of the learned environment was intentionally disrupted by the procedures such that participants had to rely on long-term memory for their reasoning. Therefore, the degree to which any transient representation was used had to be in the form of a new transient representation of current position.

More important, our results are agnostic with respect to the tenets of the dual representation theory and may be accounted for by most models if they can be sufficiently specified to incorporate the potential influence of current position. It seems clear that to interrogate spatial memory, one needs to bring the relevant space to mind in working memory and then reason about that space. We are essentially suggesting that in addition to whatever information they are using from long-term memory, people have an understanding of where they are currently located. A transient representation of the spatial layout for the immediate space may indeed be available, but we assert that its influence is an interaction with the long-term memory. Therefore, the critical element to seeing or not seeing sensorimotor interference is not the use of a transient or long-term representation, respectively, but whether the immediate representation of current position is incorporated into the relevant working memory representation that has been retrieved from long-term memory. This suggests that current models need to incorporate this interaction of immediate working memory representation of position with the working memory representation that comes from retrieving the long-term memory representation.

Current models clearly posit the interaction of long-term memory and transient memory in other processes such as reorientation. That is, when one reenters a space with cues available, one can use those cues and the long-term representation to infer one's position as well as the locations of other objects in the space. Here we propose that this interaction also applies to the ambiguous situation of the present study, in which participants reentered the room but had no cues to define their location and orientation within the space. At most, our participants knew they were standing at the perimeter in a room structurally similar (i.e., circular) to the one they had studied. Participants could have used one of several strategies to address their position in the room. First, participants could simply remain agnostic with respect to actual position (no disambiguation) and default to the long-term representation without any interference from a current position. Second, they could use their long-term memory representation to select the most accessible orientation in memory—the learned orientation. Our data suggest that the participants in the *different room* groups ignored the room and used their long-term representation based on the preferred view at 0° and the relatively lower cost for novel orientations. However, in our *same room* groups, there was a

relatively larger cost and two preferred orientations depending on whether they stayed at the learned view (best performance at 0° orientation) or updated to 180° (best performance at 180° orientation). These results suggest a third method for disambiguating position in which participants in the *same room* groups were interrogating long-term memory in the context of a current position by recalling the last known (salient) orientation in the space.

There are several important implications of these studies, beginning with the questions they raise about the stability of long-term memory representations. Although we have firm evidence for the establishment of a preferred orientation (in this case at the learned orientation) based on the persistent reliance on this orientation in all the *different room* instruction groups, the flexibility in this preference under *same room* instructions suggests an interaction between the long-term representation and one's knowledge of one's current position in real space (see also Kelly et al., 2007; Waller & Hodgson, 2006; Wang & Brockmole, 2003a, 2003b; Wang & Spelke, 2000). Notably, the map drawing data suggest that the same participants who showed an advantage for the updated view (180°) defaulted to the expected long-term preferred orientation (0°) once they were out of the room. However, these results should be interpreted cautiously given that map drawing or model building may rely on a separate visual or eidetic representation (e.g., Shelton & McNamara, 2004a). The stronger case for suggesting that the *update–same room* group likely had a long-term representation with a reference frame at the learned orientation is the fact that this group was identical in every way to the *update–different room* group until the point of retrieval. If there was any shift to a new reference frame, it could have occurred only at the point of retrieval and would be attributed to the need to disambiguate the testing condition. This shift would provide further evidence for the interaction of current position with the retrieval of the long-term memory representation. Future investigations using follow-up sessions might be able to assess whether shifts in preferred orientation due to prior updating under *same room* instructions have any lasting effects on subsequent performance.

One of the striking results of our study was the use of the last known or salient position when interrogating long-term memory under *same room* instructions, suggesting that this information must be present in the representation of the space. In addition to the enduring long-term representation suggested by current models,[5] with features such as a stable reference frame and fixed locations of landmarks and objects, we suggest that memory must also allow for malleable features. It is unlikely that one constantly change one's representation of any given space, but one may update the locations of unstable features to allow more efficient use of memory. We do not propose that features of the environment must fall strictly into these two categories. For example, an object can have a stable location (e.g., the monitor on my desk) or occupy different locations from day to day (e.g., my hot chocolate mug). In the latter category, the location may or may not be represented, depending on the situational requirements (Where is my mug, anyway?). The key point is that one can incorporate these malleable features into one's established long-term representation in a flexible manner—a handy feature for a system that needs to be able to accommodate a variety of goals.

Last known position may be a particularly interesting malleable feature because it depends on one's interaction with the stable components of the space. For many spaces, the last known position is the point of exit, which has a high probability of being the point of reentry. By maintaining this information, one could reduce the burden associated with reorienting in a space upon reentry. Our data suggest that people assume this statistically probable position when the conditions of reentry are ambiguous. In this model, it is also possible that the last salient position is stored. For example, the exit or entry point in a familiar parking lot is probably not changing and would be part of the enduring representation, so the critical malleable information is one's parking spot. In our study, the updating condition emphasized a new position, but participants were not asked to do anything after completing the updating. This may have given rise to speculations on the part of our participants about the purpose of updating and the updated position, making it salient. Whether salient or most recent is the relevant property, these cases reflect a memory system that allows for updating of malleable features within a stable representation. These effects cannot be attributed to working memory given that people are clearly able to maintain this information over long periods that include a variety of distractions, disorientation, etc. Although we recognize that most people will find this kind of malleable storage intuitive, our empirical demonstration of its role in retrieval suggests it is an important element to spatial memory.

Finally, it is important to note that these are effects associated with long-term memory retrieval. All our critical manipulations were introduced after the locations had been learned. There is no grounding for suggesting that participants in the *same room* versus *different room* instruction groups had encoded the space differently because they were differentiated only at the point of starting the retrieval tasks. Similarly, the updating manipulation followed the rigorous encoding. One might still argue that updating could alter the final product of encoding; however, our *update–different room* condition argues against such an effect. That is, updating at the end of encoding had an effect when in the *same room* with no disorientation (Experiment 2) or with *same room* instructions after disorientation but had no effect on the *different room* condition, even though the updating procedures were identical. Again, the only difference between the two instruction groups was the difference introduced at retrieval, several minutes after the encoding and nonvisual updating had occurred.

One need not posit parapsychological phenomena to understand that one can sometimes feel mentally transported to another place or time. Here we demonstrated that this kind of mental travel may be a natural part of one's spatial memory processes. Even the notion of one's own current position appears to be flexible and dependent on instructions. Taken together, these striking results provide a new and important element to the spatial memory literature by emphasizing the importance of the conceptual testing environment, malleable versus stable features, and the interaction of long-term memory and with expectations about current position.

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[5] It is possible that long-term memories are updated when there is some sort of relearning. For example, in Shelton and McNamara (2001a) participants could select from different learn views to find the best orientation for representing the space. Presumably, a similar updating could occur at longer intervals, but this has not been empirically tested to our knowledge. Moreover, it is not the kind of updating that occurs in the transient representation and is not playing any obvious role in the data presented here.

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